



Two-Dimensional Simulation of Truckee River Hydrodynamics

by Stephen H. Scott

PURPOSE: The purpose of this Coastal and Hydraulics Engineering Technical Note (CHETN) is to demonstrate the use of multidimensional hydrodynamic models for assisting in riverine restoration design. A two-dimensional (2-D) hydrodynamic model was applied to the McCarran Ranch reach of the Truckee River to evaluate existing condition and future restoration plan condition hydraulics. The impact of the restoration design is presented in terms of the difference in the existing and plan condition hydraulic variables such as bed shear stress, velocity magnitude, and water surface elevation.

BACKGROUND: A previous study in the Arid Regions Research Program evaluated the stability of a proposed restoration design in the McCarran Ranch reach of the Truckee River (Scott 2006). For this effort, a simple computer program, SAM, was utilized to evaluate the stability of the restoration design cross section. The sediment transport capacity was computed for the existing and design channel geometries for a series of probabilistic return flood flows. The results of the study indicated that the design cross section would be depositional.

Although this method of analysis is applicable for a reconnaissance level analysis, it is not sufficient to address the impacts of channel planform and potential bed changes associated with sediment transport. The hydraulics of the SAM study were based on normal depth calculations, which represent an ideal channel (channel cross section and slope do not change with distance). In reality, the McCarran Ranch reach of the Truckee River experiences nonuniform flow as the result of varying cross section geometry and bed slope through the reach. The 2-D effects of this reach cannot be reliably simulated with one-dimensional (1-D) models. The channel transitions from a confined channel upstream of McCarran Ranch to an unconfined channel for which overbank flooding occurs in adjacent wetlands. At high flows, this overbank flooding reduces the energy slope through the lower reach resulting in lower channel velocities and, thus, lowering the sediment transport capacity. A 2-D model application is necessary to capture these spatial flow phenomena and to accurately represent the system hydrodynamics.

This report details the application of a 2-D hydrodynamic model to the McCarran Ranch reach of the Truckee River. Five steady-state probabilistic return flood flows were simulated for this reach. The hydrodynamics of these simulations are discussed, along with sediment transport potential based on the results. At the present time, no model verification data are available, thus these results should be considered preliminary and therefore only represent relative trends between the varying flow simulations.

MODEL DESCRIPTION: The model used in this study was a 2-D hydrodynamic and sediment transport model capable of simulating unsteady turbulent open-channel flow. The hydrodynamic model is capable of simulating subcritical, critical, and supercritical flow, as well as mixed regime

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flow. Three numerical schemes are available for simulating turbulence closure: a parabolic eddy viscosity model, a mixing length eddy viscosity model, and a k-epsilon turbulence model.

The sediment transport component of the model has the capability to simulate nonuniform sediment transport with multiple grain sizes and a multilayered bed. The model offers the option of fully unsteady or quasisteady computations. The quasisteady module assumes that the hydraulics are gradually varying over time, thus, steady-state conditions can be assumed at each time-step. This is primarily applicable to large rivers with slowly varying hydrographs.

ANALYSIS: The Truckee River originates from Lake Tahoe, flowing 140 miles (225 km) through Reno, NV, to Pyramid Lake. The downstream boundary of the modeling reach is located at river mile (RM) 40 as referenced from Pyramid Lake (Figure 1). The study reach is approximately 3.6 miles (5.8 km) in length, with the upstream boundary located at RM 43.6, which is approximately 7 miles (11 km) downstream of Vista, NV.

A numerical mesh was constructed of the area (Figure 2). The mesh consisted of 54,000 computational nodes. The main channel and overbank roughness used in the simulations was 0.039 and 0.066 Manning's n respectively. The mesh was designed to include overbank elevations up to approximately 1,310 m (4,297 ft) mean sea level (msl) in the McCarran Ranch area (Figure 3).

Five probabilistic return flows (2-, 5-, 10-, 25-, and 100-year) were computed for the Vista gauge discharge record using the Log Pearson method. The downstream stage boundary for the 2-D model was obtained by simulating backwater profiles for the Truckee River using Hydraulic Engineering Center – River Analysis System (HEC-RAS), a 1-D hydrodynamic model. The HEC-RAS model was obtained from the U.S. Army Engineer District, Sacramento. The discharge and stage boundary data are found in Table 1.

Contour plots for the 2-year return flow event are found in Figures 4-6, with the remaining four flow events found in Figures 11-22. For each event, the water surface elevation, flow velocity, and bed shear stress magnitude are shown in contour.

The 2-year return event, 85 cu m/sec (2,999 cfs), represents the approximate bankfull discharge for this reach. Although the contour plots show water on the overbank areas, it is not connected to the main channel. These areas are the result of initial high-water surface elevations that were used to stabilize the model until it reaches steady state. The gray colored contour on the grid indicates dry areas. On the average, flow velocities ranged from 1.0 to 1.5 m/sec (3.3–4.9 ft/sec), with some of the steeper areas showing velocities up to 2.0 m/sec (6.6 ft/sec). On the average, the bed shear stress magnitude was between 20 and 30 Pa (0.42 – 0.63 lb / ft²).

Overbank flow begins for the 5-year flow event (170 cu m/sec, 5,999 cfs) in the lower part of the McCarran Ranch reach (Figures 11-22). As the discharge increases, the overbank flows increase, particularly just preceding and throughout the bendway located at RM 41.1. This overbank flooding reduces the energy slope through the reach, lowering the velocity and bed shear stress. However, the velocity and bed shear stress in the channel above the McCarran Ranch reach continues to increase with increased flow, with velocities in excess of 3.0 m/sec (9.8 ft/sec) and bed shear stress ranging from 50 to 120 Pa (1.0 – 2.5 lb/ft²) for the 25- and 100-year events. Figures 7 and 8 show the flow velocity magnitude and direction for the 2-year and 100-year flow events in the vicinity of the

bendway. Because of the overbank flooding, the main channel flow velocities are in the same approximate range. The impact of overbank flooding on the hydrodynamics is clearly shown in Figure 9. This is a plot of the water-surface profiles for the flow events. Note that the energy slope through the McCarran Ranch reach is reduced for the 25- and 100-year flow events, while the upstream energy slope remains relatively constant.

POTENTIAL IMPACTS AS RELATED TO CHANNEL RESTORATION: Figure 10 depicts the bed sediment size distribution for the McCarran Ranch reach as reported by Otis Bay Consulting to the Sacramento District. The bed consists primarily of gravel and cobble size sediments, with a median grain size of approximately 64 mm (2.5 in.). Table 2 is the critical shear stress for mobilization of gravel and cobble as reported by Julien (Julien 1995). The range of critical bed shear stress for medium to very coarse gravel ranges from approximately 6.0 to 26.0 Pa (0.13–0.54 lb/ft²), and for small to large cobbles the range is 53.0 to 111.0 Pa (1.1–2.3 lb/ft²). Based on the model hydrodynamic results and the assumption that the gravel fraction is armored by the cobble sized sediments, it appears that the critical threshold for bed motion would occur for the 25-year event upstream of the McCarran Ranch restoration site (bed shear stress between 50 and 120 Pa (1.0–2.5 lb/ft²)). However, because of overbank flooding, the bed shear stress in the lower reach adjacent to the bendway is less than required to mobilize the cobble armor layer (10–20 Pa, 0.21–0.42 lb/ft²). The consequence of this is that the McCarran Ranch reach will be depositional for both the gravel and cobble sized fractions during flood events greater than or equal to the 25-year return flow. This analysis indicates that restoration designs that increase the number of meanders or reduce the channel capacity will only serve to exacerbate sedimentation in the lower McCarran Ranch reach.

CONCLUSIONS AND RECOMMENDATIONS: The hydrodynamic modeling results indicate that overbank flooding in the McCarran Ranch reach of the Truckee River will significantly reduce the sediment transport capacity, particularly in the bendway located at RM 41.1. The sedimentation potential increases with flood severity, with the greatest potential for flood flows greater than or equal to the 25-year return flood event. Channel restoration efforts that increase the form roughness by increasing the number of meanders or reducing the cross-sectional area of the channel will further reduce existing channel transport capacity.

It is recommended that further studies be conducted with the 2-D model. Flow velocity data collected by the Desert Research Institute (DRI) in 2004 can be used to verify model hydrodynamics. Additionally, DRI collected a number of bed sediment samples along the reach that can be utilized in the sediment model. The sediment transport model can be used to compare existing channel sedimentation with that of the restoration design.

POINT OF CONTACT: For additional information, contact Dr. Stephen Scott (601-634-2371, email: Steve.H.Scott@erdc.usace.army.mil) of the Coastal and Hydraulics Laboratory, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

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- Scott, S. H. 2006. *Application of the SAM computer program for Truckee River stable channel analysis*. ERDC/CHL CHETN-VII-7, Vicksburg, MS: U.S. Army Engineer Research and Development Center.
- Julien, P. Y. 1995. *Erosion and sedimentation*. Cambridge University Press.

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Table 1
Probabilistic Return Flow Event Simulations with Boundary Conditions

Flow Event	Discharge m ³ /sec – ft ³ /sec	Downstream Stage m - ft
2-Year	85 – 2,999	1,300.8 – 4,266.6
5-Year	170 – 5,999	1,301.5 – 4,268.9
10-Year	245 – 8,645	1,301.9 – 4,270.2
25-Year	366 – 12,915	1,302.4 – 4,271.9
100-Year	611 – 21,561	1,303.4 – 4,275.1

Table 2
Critical Bed Shear Stress for Mobility of Gravel and Cobble Sized Sediments (Julien 1995)

Sediment Size Class	Critical Bed Shear Stress Pa – lb/ft ²
Medium Gravel > 8 mm	5.7 – 0.02
Coarse Gravel > 16 mm	12.0 – 0.25
Very Coarse Gravel > 32 mm	26.0 – 0.54
Small Cobble > 64 mm	53.0 – 1.11
Large Cobble > >128 mm	111.0 – 2.32

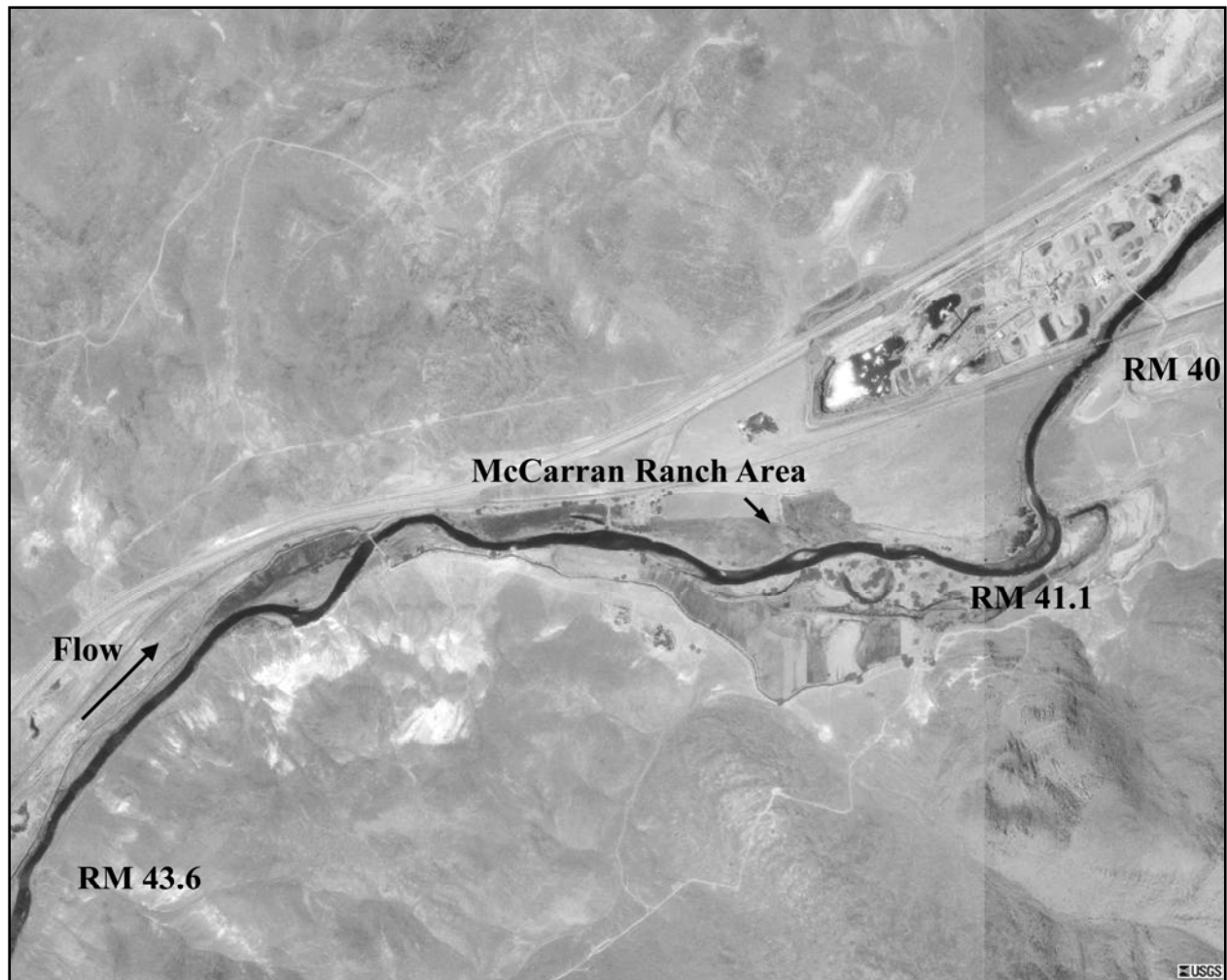


Figure 1. Aerial photograph of Truckee River modeling area

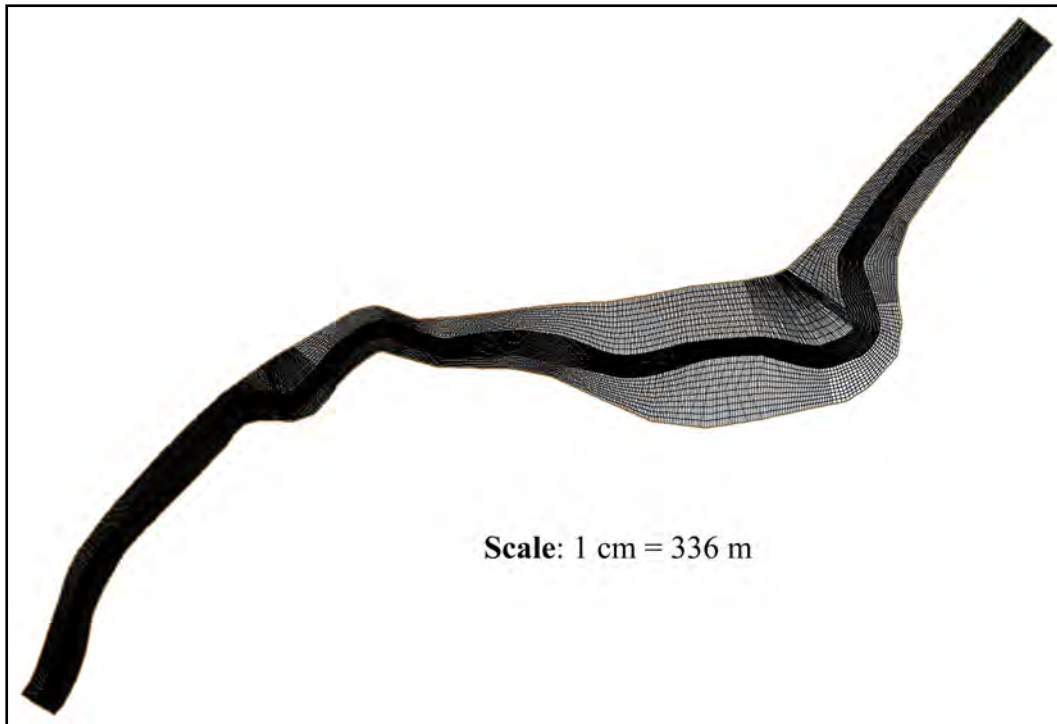


Figure 2. Two-dimensional model mesh

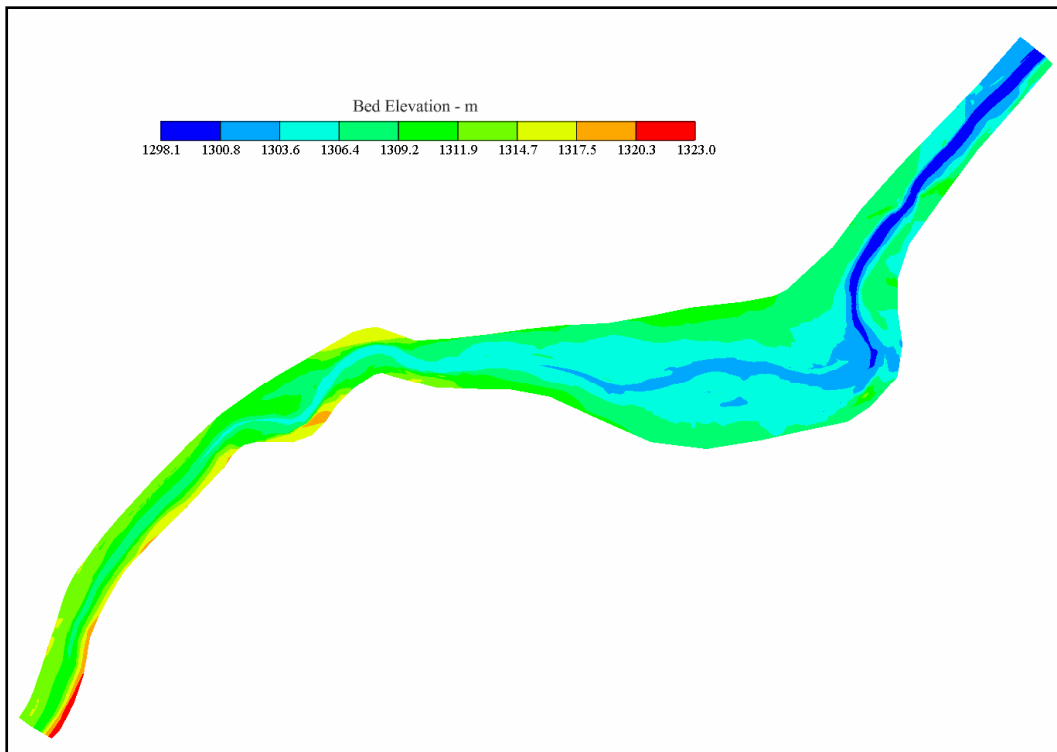


Figure 3. Model bathymetry

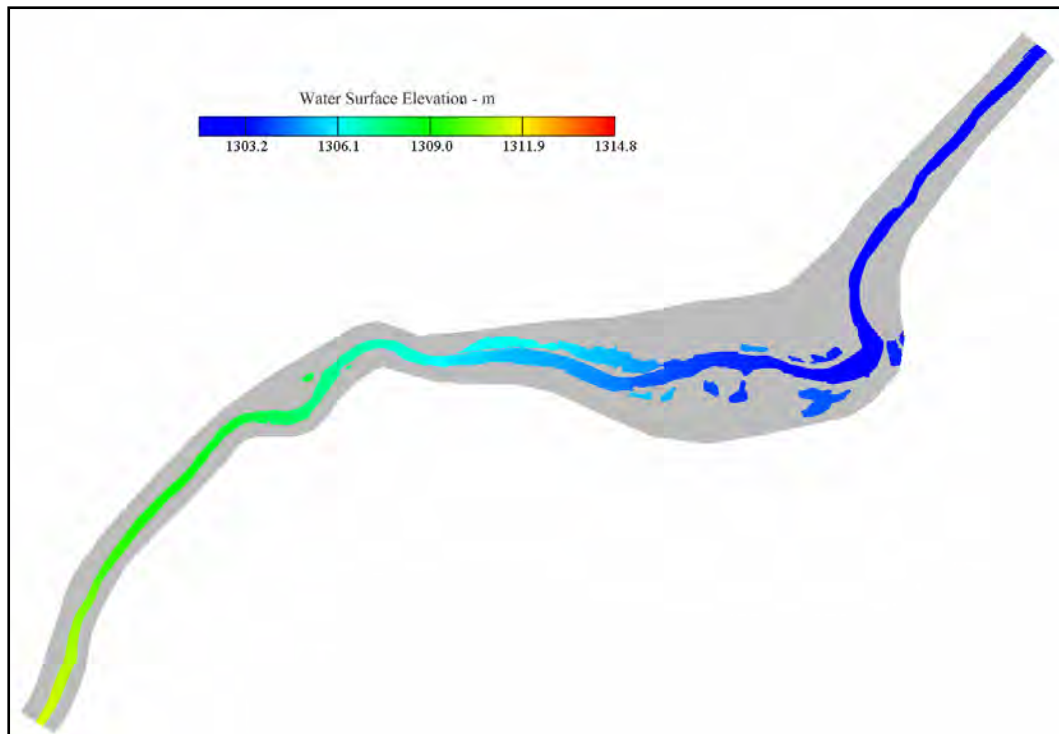


Figure 4. Water-surface elevation for the 2-year return flow simulation

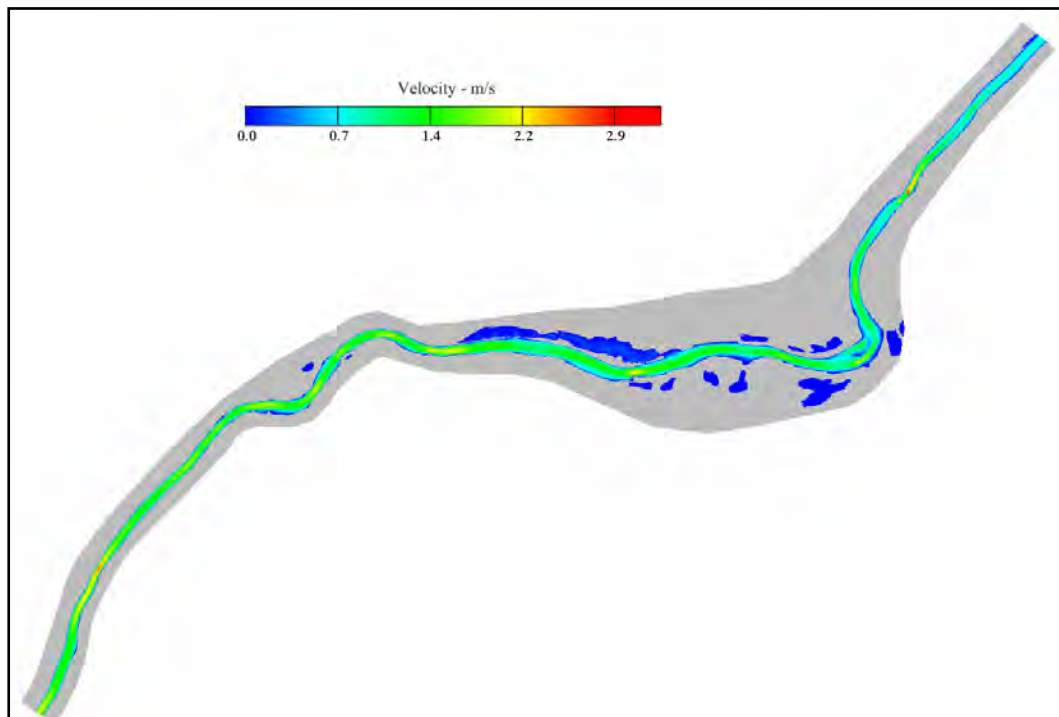


Figure 5. Flow velocity for 2-year return flow simulation

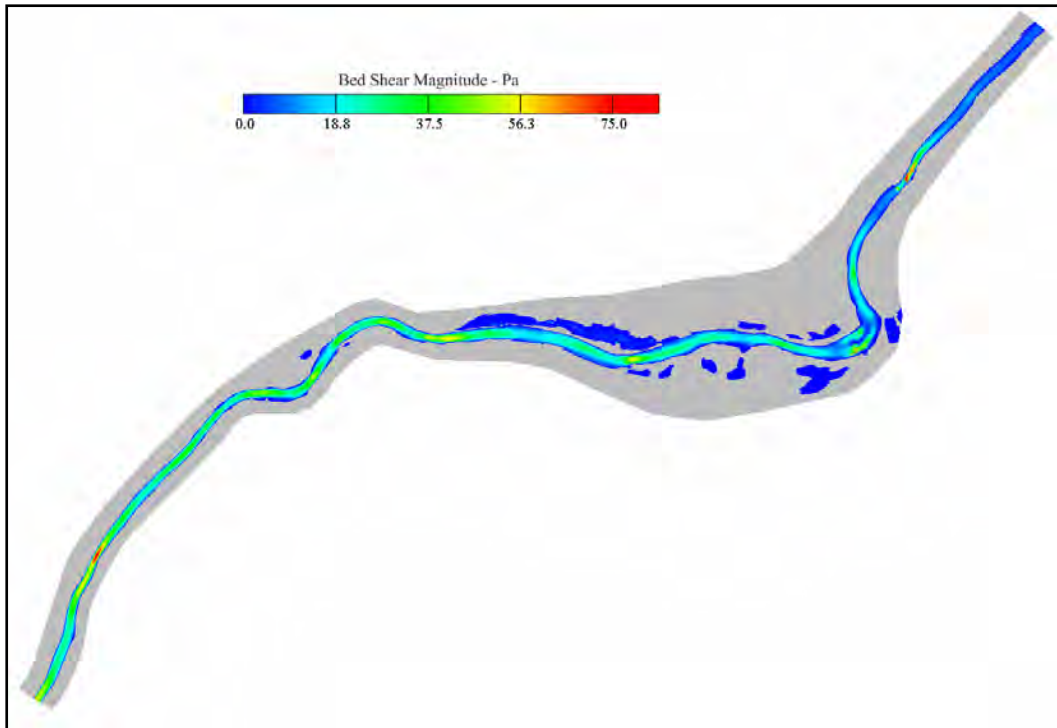


Figure 6. Bed shear stress for the 2-year return flow simulation

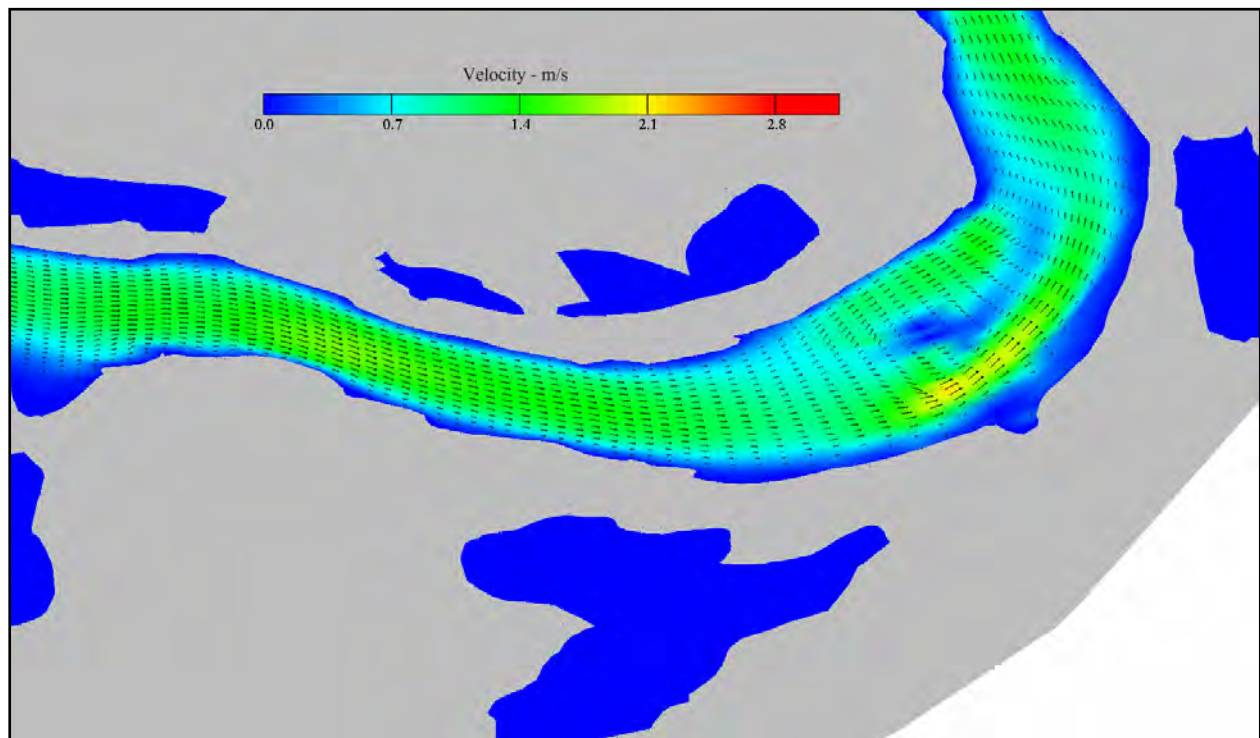


Figure 7. Velocity magnitude and direction for the lower McCarran Ranch reach for 2-year return flow simulation

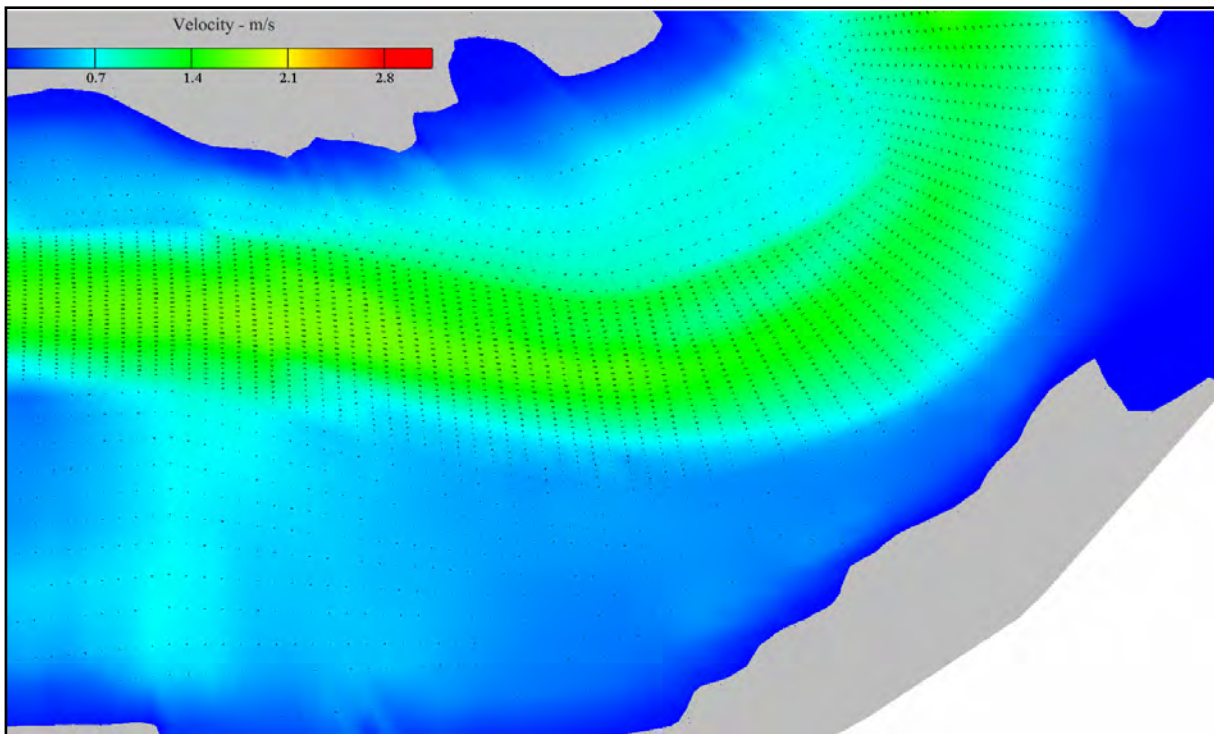


Figure 8. Velocity magnitude and direction for lower McCarran Ranch reach for the 100-year return flow simulation

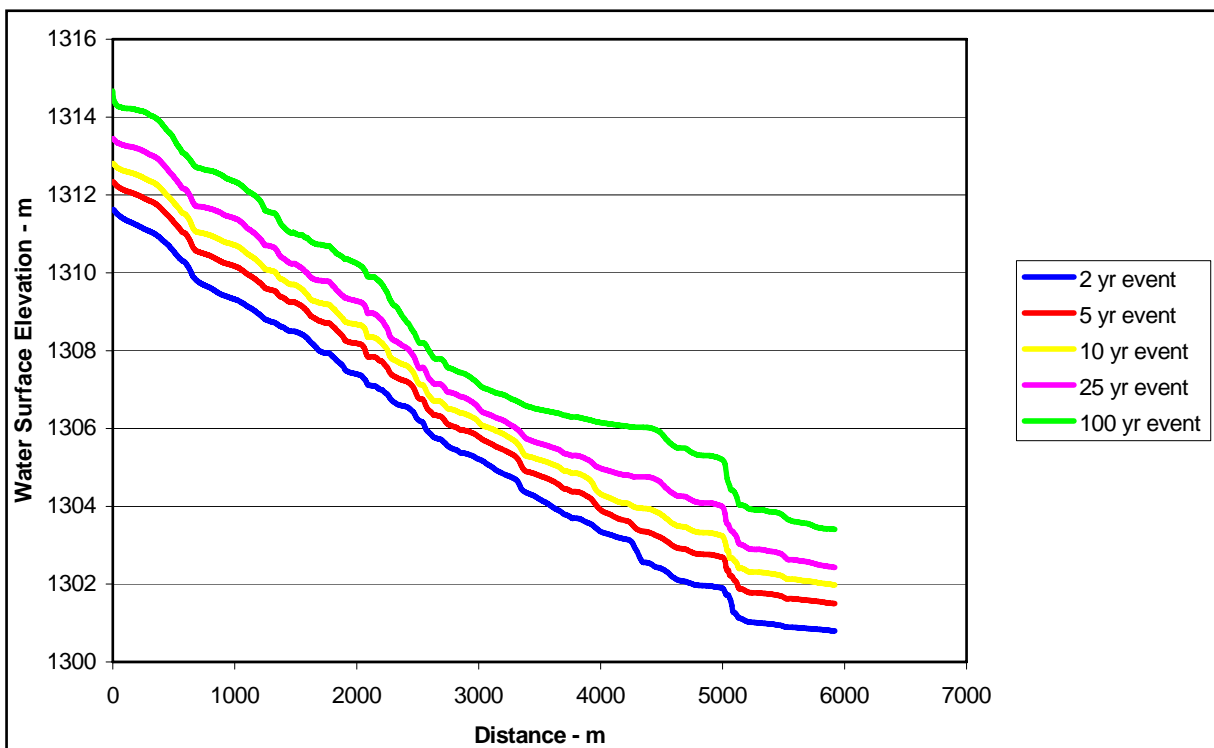


Figure 9. Water-surface profiles for probabilistic return flow simulations

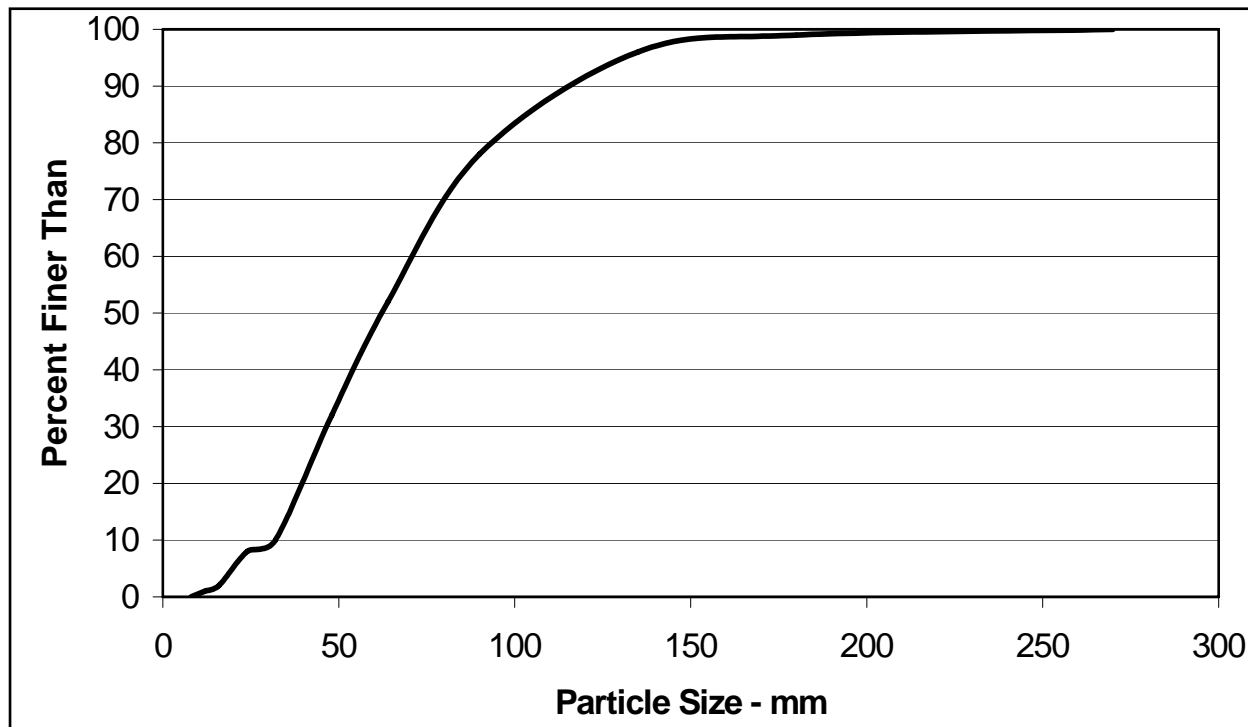


Figure 10. Bed sediment size distributions for McCarran Ranch reach as reported by Otis Bay Consultants

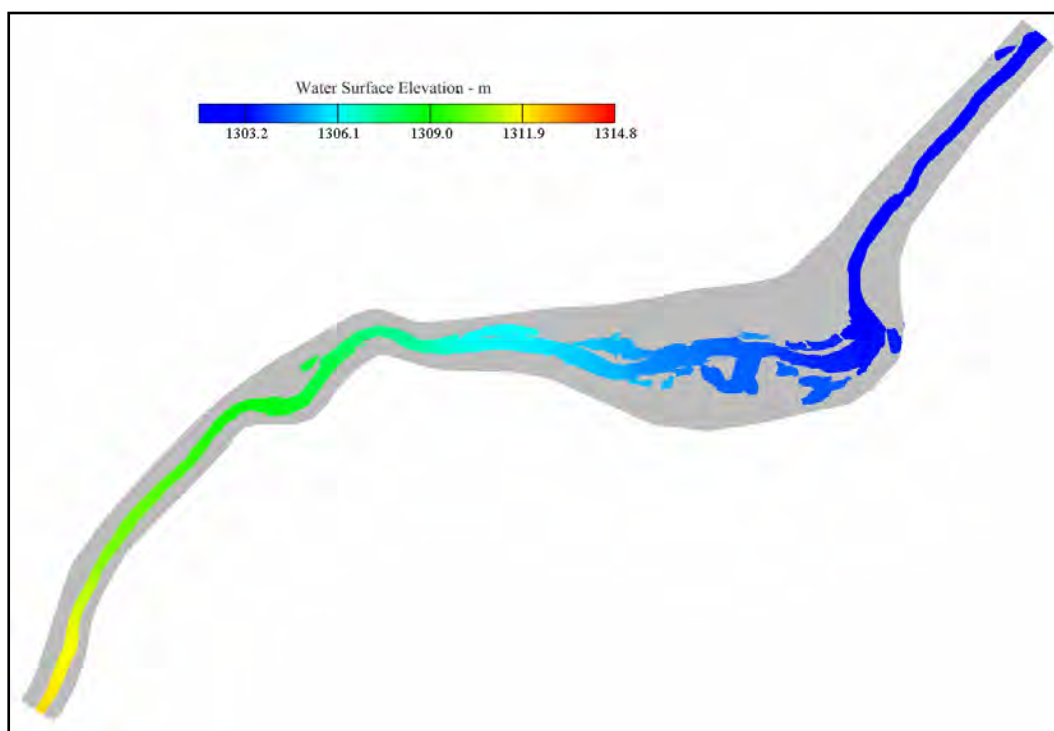


Figure 11. Water-surface elevation for 5-year return flow event

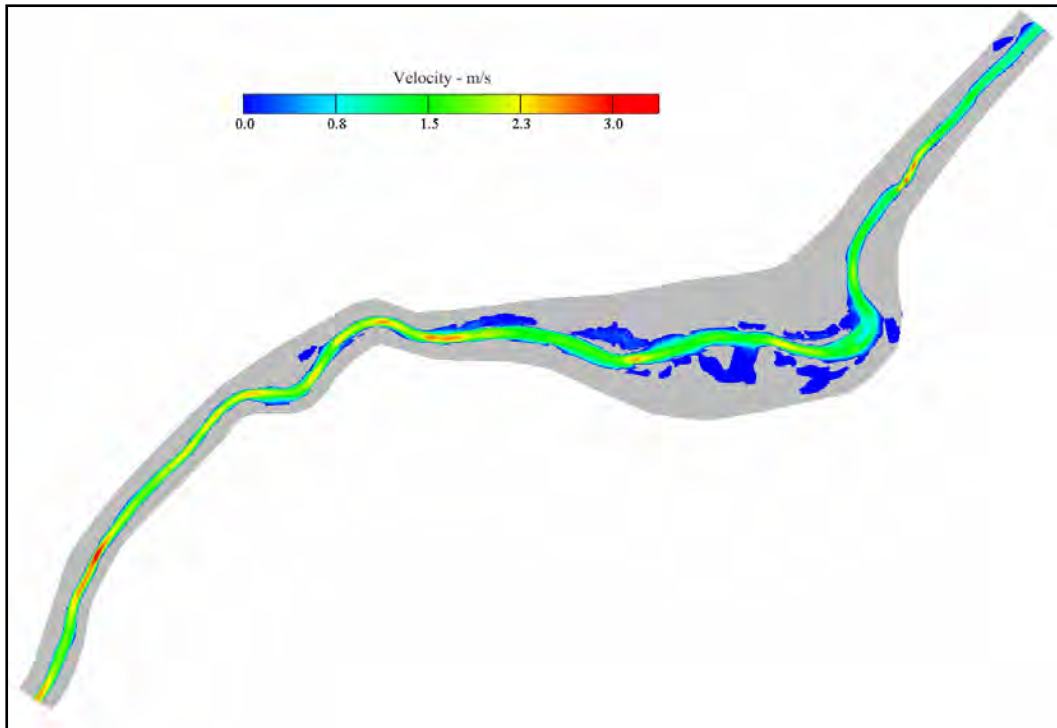


Figure 12. Flow velocity for 5-year return flow event

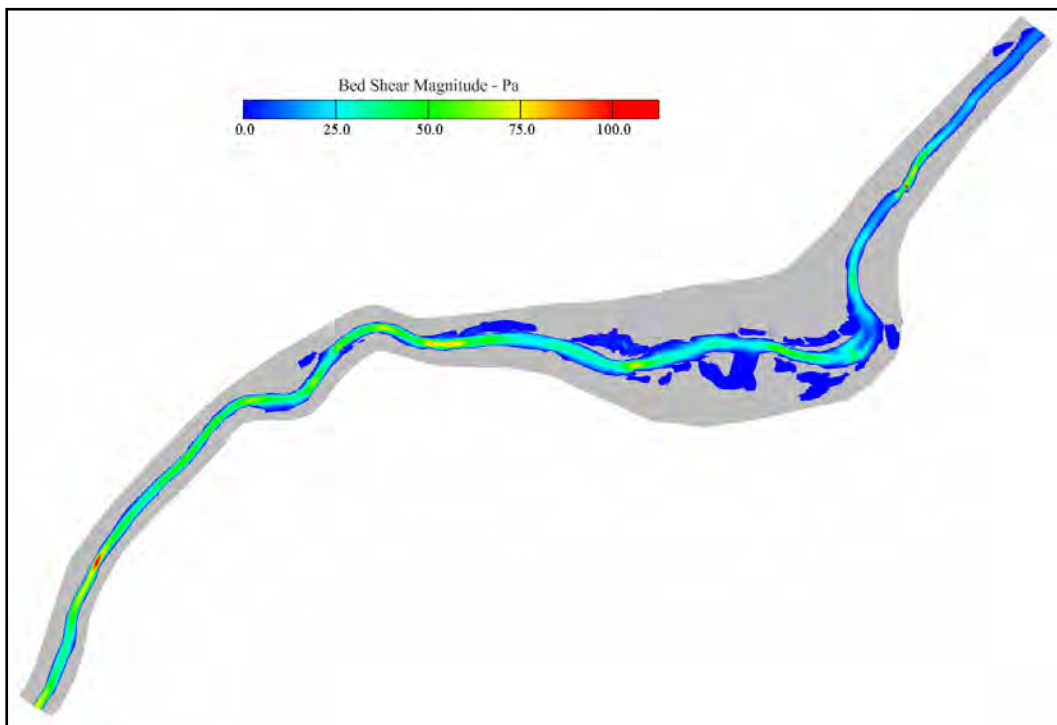


Figure 13. Bed shear stress for 5-year return flow event

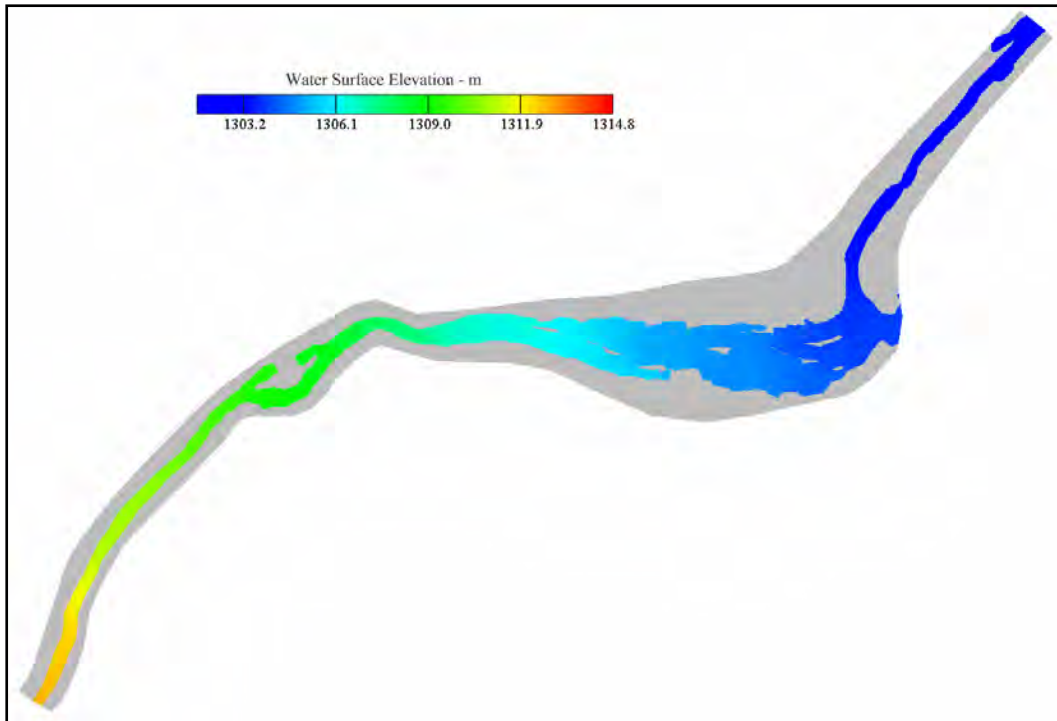


Figure 14. Water-surface elevation for 10-year return flow event

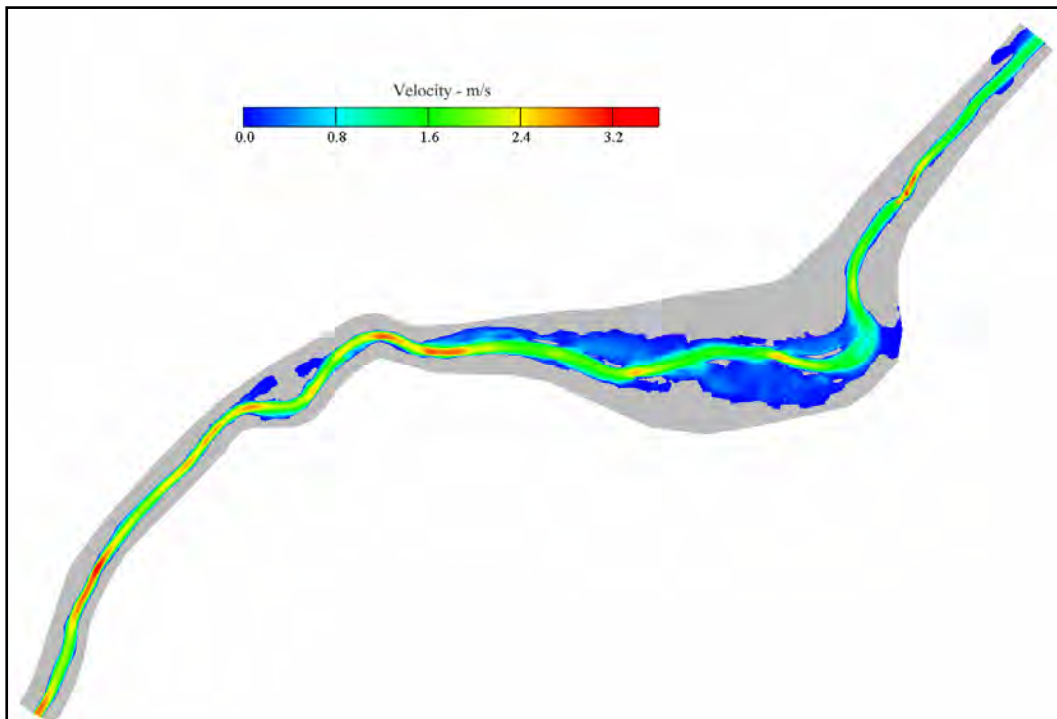


Figure 15. Flow velocity for 10-year return flow event

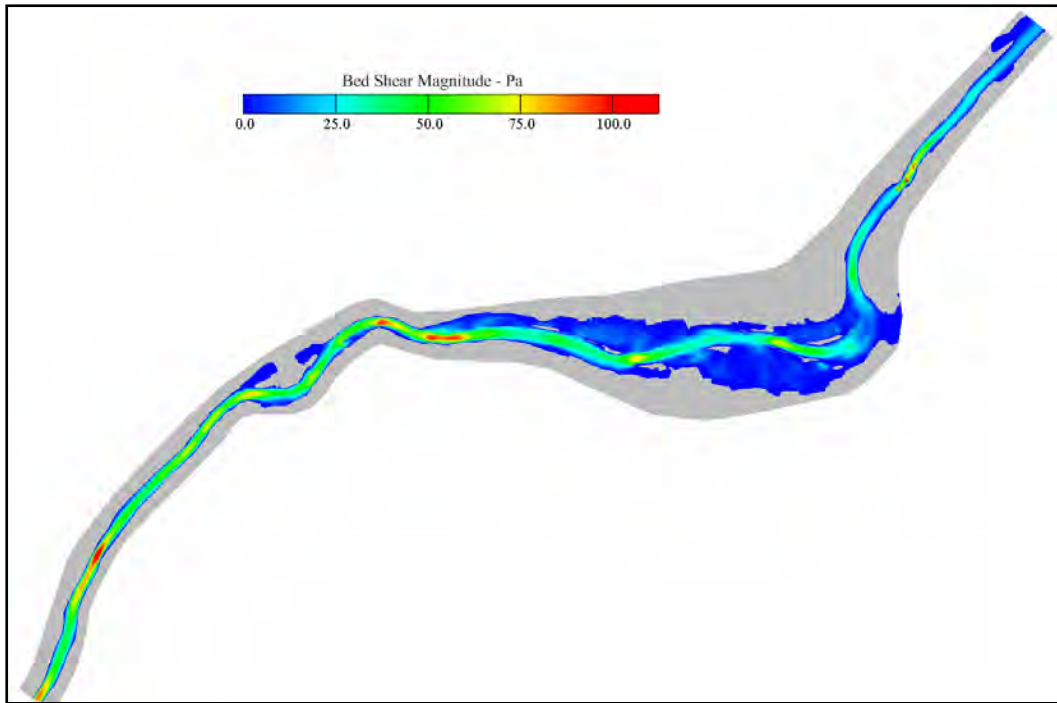


Figure 16. Bed shear stress for 10-year return flow event

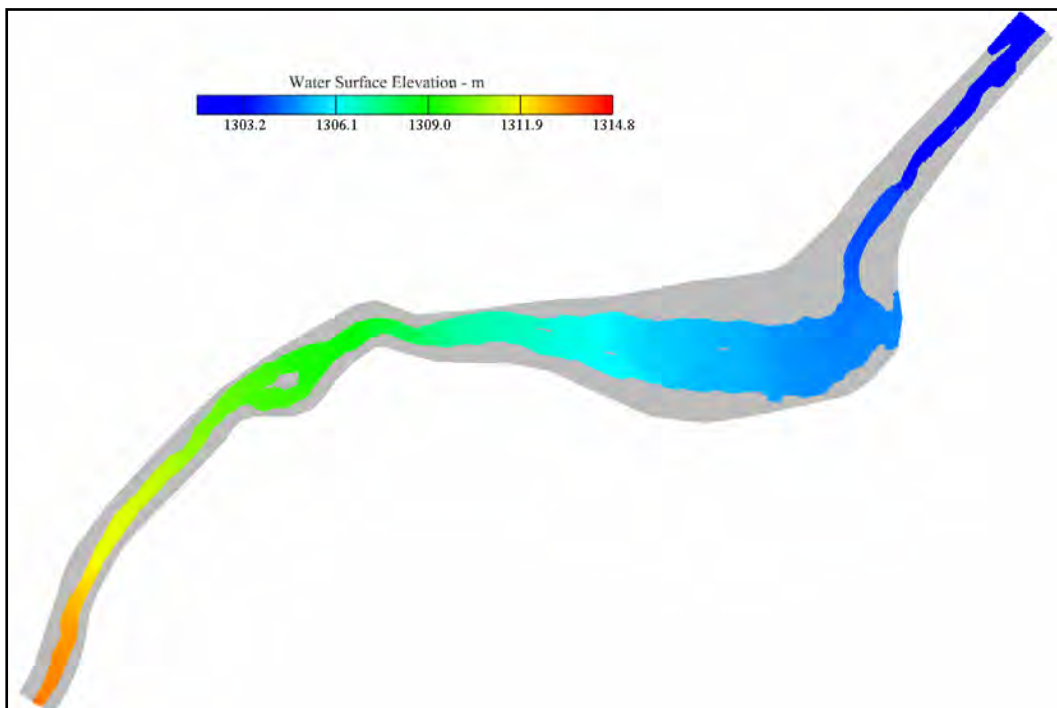


Figure 17. Water-surface elevation for 25-year return flow event simulation

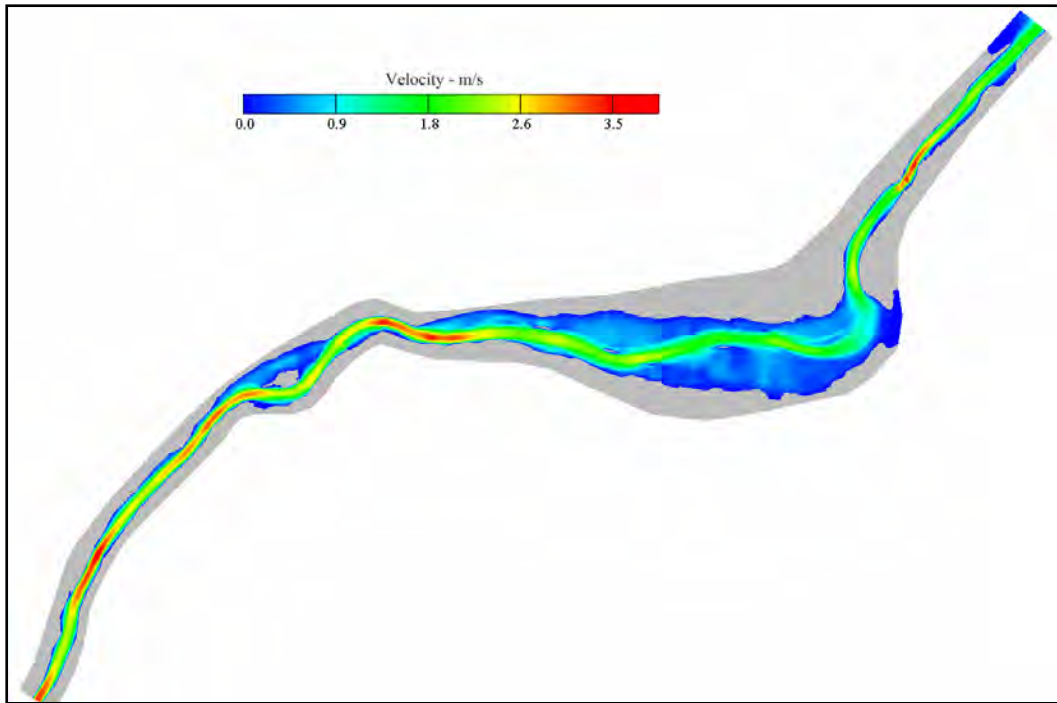


Figure 18. Flow velocity for 25-year return flow event simulation

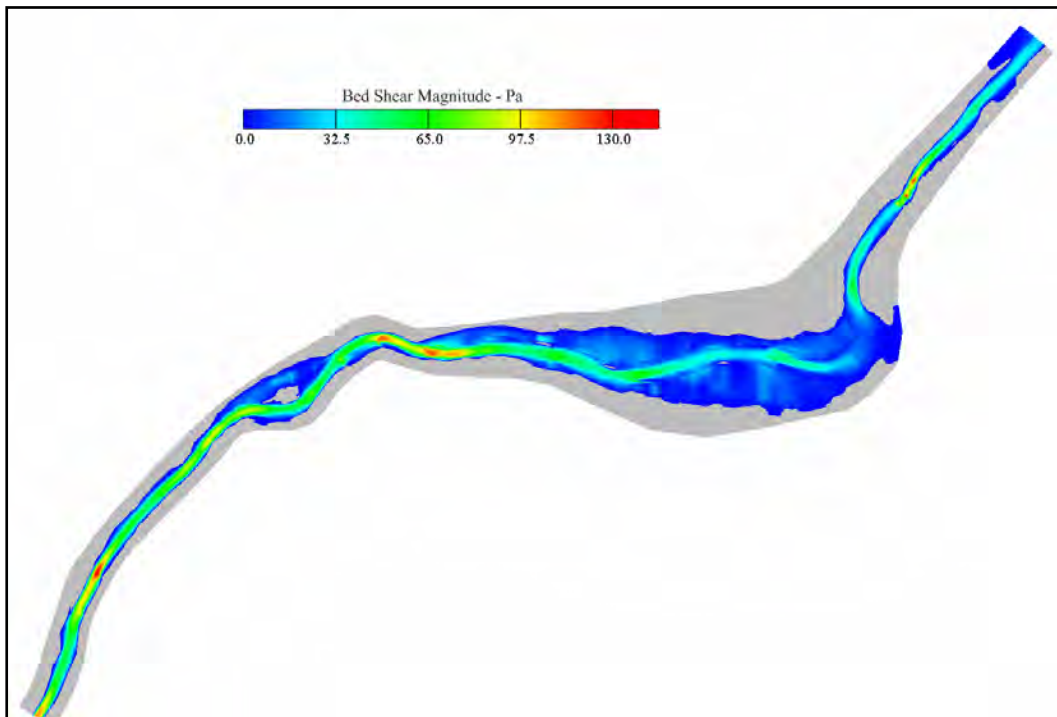


Figure 19. Bed shear stress for 25-year return flow event simulation

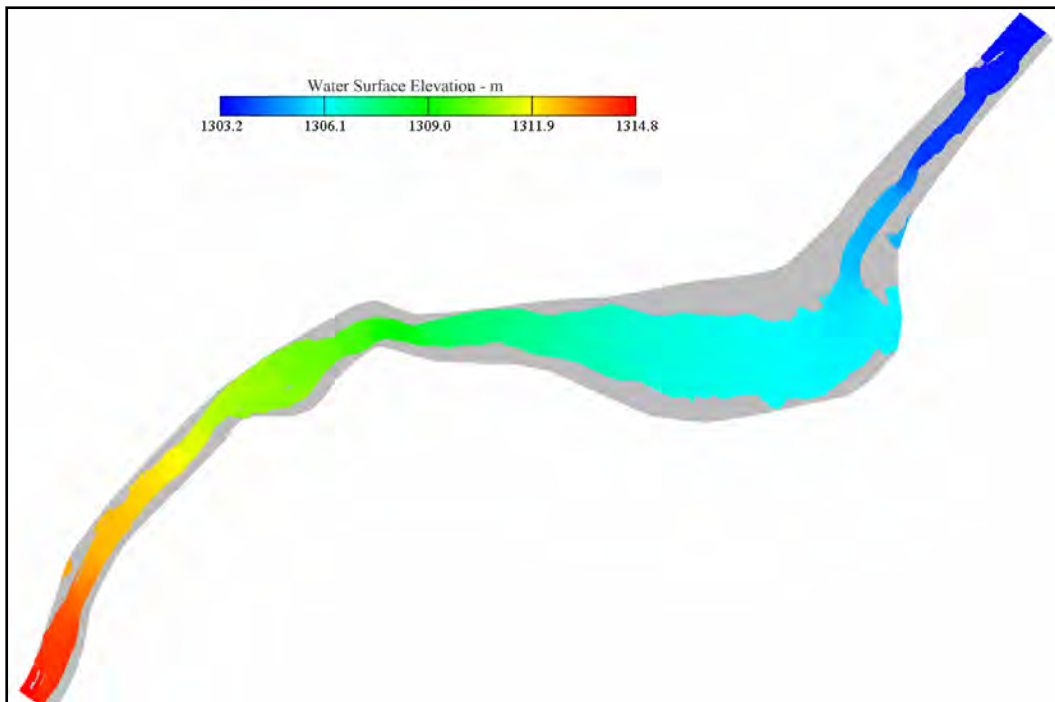


Figure 20. Water-surface elevation for 100-year return flow event simulation

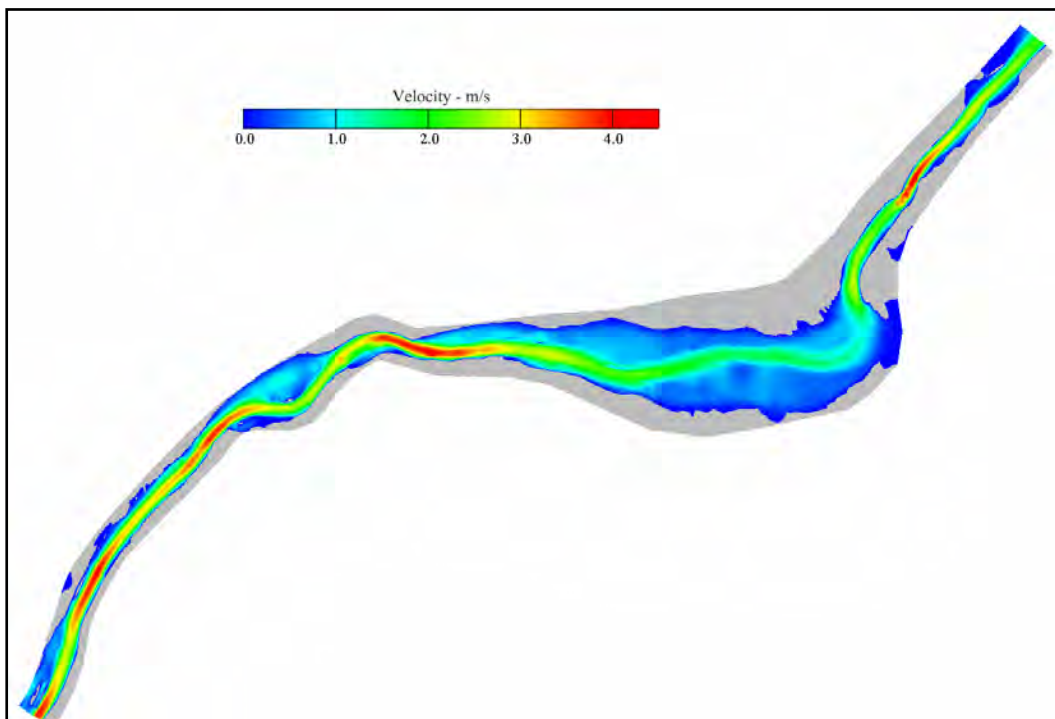


Figure 21. Flow velocity for 100-year return flow event simulation

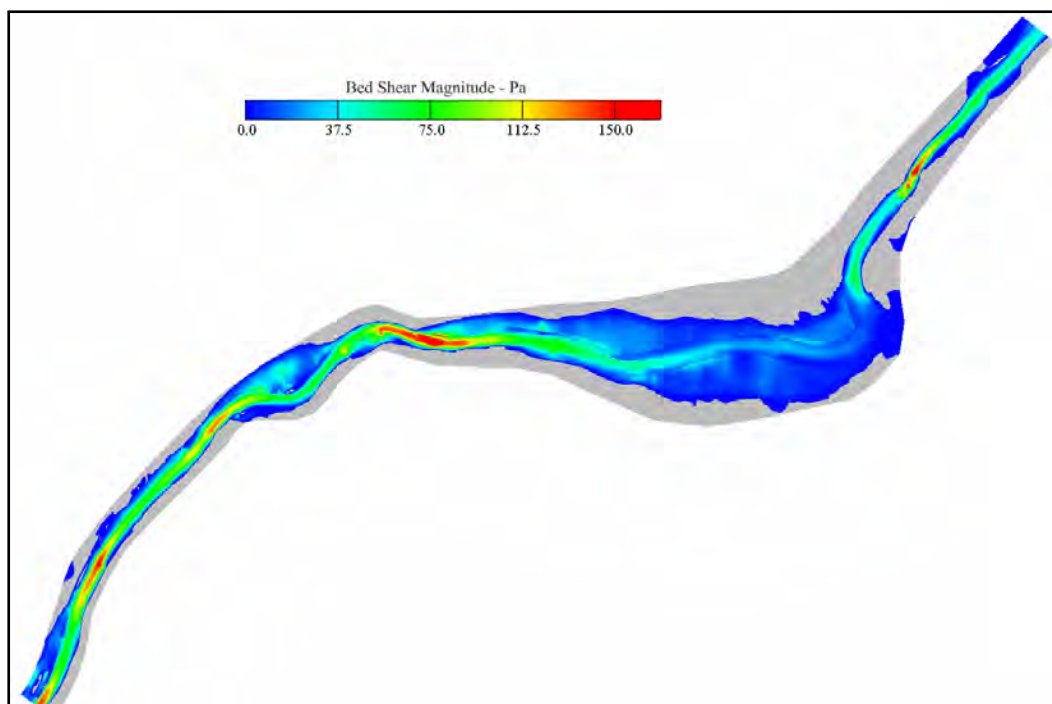


Figure 22. Bed shear stress for 100-year return flow event simulation